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FEED INGREDIENTS FOR CARNIVOROUS FISH SPECIES
ALTERNATIVES TO FISHMEAL AND OTHER FISHERY RESOURCES

by

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This document was prepared as part of the ongoing activities of the FAO Inland Water Resources and Aquaculture Service to help to meet the needs of aquaculture workers of Member Countries for synthesis of information in the field of aquaculture nutrition and feed development.

The document is based on the paper presented by the author at the First International Symposium on 'Sustainable Fish Farming' held in Oslo, Norway, 28-31 August 1994.

The document is the third of a series concerning the selection and use of feed ingredients for farmed finfish and crustaceans. The first two documents were concerned with feed ingredients for warmwater fishes (FAO Fisheries Circular No. 856) and crustaceans (FAO Fisheries Circular No. 866).

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ABSTRACT

The paper reviews the major studies conducted to date concerning the partial or total replacement of fishmeal within aquafeeds for carnivorous fish species with alternative protein sources or 'fishmeal replacers', including terrestrial animal by-products, single-cell proteins (SCP), oilseeds, grain legumes, cereal grains, and miscellaneous plant products. Information is presented concerning the nutritional value and chemical composition of the individual protein sources, together with their normal and suggested maximum dietary inclusion levels. Emphasis is placed on the important role played by feed technology and biotechnology in the development and nutritional success or not of individual fishmeal replacers, either through 1) the use of appropriate feed processing techniques for the deactivation/removal of endogenous anti-nutritional factors and/or for increasing nutrient availability and digestibility, 2) the use of dietary enzyme supplements to aid digestion within the gastro-intestinal tract and so increase nutrient availability and digestibility, 3) the use of dietary amino acid/mineral supplements, either in crystalline/purified form or coated/protected form, to overcome inherent amino acid and/or mineral imbalances, 4) the use of dietary feeding stimulants so as to enhance feed palatability and maximize feed intake, 5) the use of fermentation technology and genetic manipulation to produce single-cell proteins from waste streams with the desired dietary nutrient profile for the cultured species, and 6) the use of plant breeding programmes to produce genetically selected varieties low in specific anti-nutritional factors or high in specific essential nutrients.

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1. INTRODUCTION

Finfish and crustacean farming systems, like all animal food production systems, are dependent upon the market availability of agricultural and fishery resources for the provision of dietary nutrient or feed inputs. It follows therefore that if fish and crustacean aquaculture production is to be sustained at its present growth rate of about 7.5% per annum (Table 1, Figures 1-2) into the coming millennium then equivalent amounts of fertilizer and feed inputs will have to be provided. However, although the aquaculture sector has been successful in the past in competing with livestock (ie. poultry, pigs, cattle, sheep, goats and other ruminants) and humans for these feed resources (the large majority of agricultural and fishery products employed as pond fertilizers or within compound aquafeeds also being used either as crop fertilizers, within livestock feeds, or used for human consumption) this may not be the case in the future as farming systems intensify and the demand for a finite pool of agricultural and fishery resources increases; poultry and pig meat production within developing countries during the period 1970-1990 was reported to be increasing at a rate of 7.0% and 6.1%, respectively (FAO 1993).

In particular, intensive farming systems for carnivorous fish and shrimp species (ie. salmon, trout, eel, yellowtail, turbot, seabass, seabream, marine flatfish, and marine shrimp etc.) are currently totally dependent upon the use of fishmeal and other fishery resources as the sole or major source of dietary protein and lipid within formulated compound aquafeeds (Bimbo & Crowther, 1992; Chamberlain 1993; Rumsey 1994; Tacon 1994; Wijkstrom and New 1989). For example, fishery products generally make up about 70% by weight of compound aquafeeds for most farmed carnivorous fish species (ie. mainly in the form of high quality fishmeals, fish oil, and to a lesser extent fish protein hydrolysates; Tacon 1993) and about 50% by weight of compound aquafeeds for marine shrimp (ie. mainly fishmeal, fish oil, shrimp meal, squid liver meal, and to a lesser extent krill meal, fish protein hydrolysates, and fish/shrimp silages; Tacon 1993a). Moreover, although carnivorous fish species represent only 12% of total finfish aquaculture production in 1992 (ie. 1,132,063 metric tonnes; Table 2, Figure 3) they consumed about 660,000 mt of fishmeal (as compared with about 73,000 mt consumed within aquafeeds for omnivorous/herbivorous fish species) or about 11% of total world fishmeal production (Table 3); 660,000 mt of fishmeal being equivalent to the use of 3,300,000 mt of small pelagics (ie. anchovy, jack mackerel, pilchard, menhaden, capelin, tuna, herring, sardine etc.) for the production of just over one million metric tonnes of cultured carnivorous finfish! It follows from this therefore that all intensive farming systems for carnivorous finfish species (the majority of which are realised within 'developed' countries) are net fish protein 'reducers' rather than net fish protein 'producers'. This is in sharp contrast to the net fish protein producing semi-intensive farming systems employed by farmers within developing countries for the production of warmwater herbivorous/omnivorous fish species; freshwater cyprinids constituting over 70% of aquaculture finfish production (Figures 4 & 5) and occupying the top four places of the aquaculture fish and crustacean production table in 1992 (Table 4, Fig. 6).

The present use of high dietary inclusion levels of marine fishery products within compound aquafeeds for finfish has been due to their almost ideal nutritional composition and quality (ie. making the formulation of the aquafeed much simpler and easier) and ready market availability throughout the year. Furthermore, and more importantly, their use has been facilitated by the generally high market value of most cultured carnivorous finfish species (as compared with the majority of warmwater herbivorous/omnivorous fish species) which makes the purchase and dietary use of these relatively expensive feed ingredients by the aquafeed compounder and/or farmer economically possible. However, whilst fishmeal represents an ideal nutritional source of dietary protein and lipid for carnivorous fish species there is an urgent need to reduce the current total dependence of the industry upon this expensive and finite commodity of uncertain supply and cost in the future; fishmeal (the largest source of animal protein available to the compound feed manufacturer) also being competitively purchased by the much larger livestock production sector (in 1990 over 86% of the world supply of fish meal was consumed within compound feeds for poultry, pigs and ruminants; Anon 1993).

Clearly, if intensive farming systems are to be sustainable in the long term it is essential that alternative and more sustainable protein sources be found for use within compound aquafeeds for these species. The aim of this paper is to review the latest developments (1986 to date) concerning the partial or total replacement of fishmeal with alternative protein sources within aquafeeds for carnivorous fish species; for a review of studies conducted prior to 1986 see Tacon (1983), and Tacon and Jackson (1985).

2. FISHMEAL REPLACERS

Fishmeal replacers include all animal and plant protein sources which have the potential to be used as a dietary replacement for fishmeal within compound animal feeds. Prior to discussing the nutritional merits of the different fishmeal replacers it should be stated at the outset that the analysis of published data concerning the use of individual fishmeal replacers is extremely difficult due to the normal absence of full feed ingredient descriptions (ie. complete definition, international feed number [IFN], feed processing method employed, particle size prior to mixing or feeding, chemical composition, etc.) reported within the large majority of feeding trials published to date. Moreover, comparative analysis between researchers and laboratories is further complicated by the use of different aquafeed manufacturing techniques (ie. cold pelleted, freeze-dried, steam pelleted, extruded feeds etc.), feed formulation techniques (purified, semi-purified, and practical diet formulations), feeding techniques (ie. fixed or satiation feeding, hand or mechanical/automatic feeders etc.), culture techniques (ie. indoor and outdoor tanks, raceways, ponds, cages etc.), fish age classes (fry, fingerlings, juveniles, growers etc), experimental test rearing period (ie. ranging from a few weeks to over one year), and fish performance (ie. slow or fast growing fish, high or low reported food conversion efficiencies; Tacon 1993b).

Table 5 summarizes the observed dietary inclusion levels of the main fishmeal replacers which have been evaluated within practical feeds for carnivorous fish species and provides suggestions for their maximum dietary inclusion level. In addition, Table 6 and Table 7 show the average reported proximate and essential amino acid (EAA) composition of the major fishmeal replacers. Finally, Table 8 shows the chemical score and limiting EAAs of the different fishmeal replacers mentioned in this review.

2.1 Terrestrial animal by-products

2.1.1 Invertebrate animal by-product meals

Only a few processed invertebrate by-product meals have been evaluated as fishmeal replacers within aquafeeds for carnivorous fish species, including:

Silkworm pupae meal (*Bombyx mori*, IFN 5-11-787: Atay 1989; Shyama & Keshavanath 1993);

Earthworm meal (*Eisenia foetida*: Cardenete et al. 1993; Stafford & Tacon 1988; Velasquez et al. 1991); and

Zooplankton mixture (freeze-dried mixture of copepods and cladocerans, 1:6 ratio: De Verga & Bohm 1992).

2.1.2 Vertebrate animal by-product meals

Terrestrial vertebrate by-product meals generally constitute the second major source of animal protein used within aquafeeds (after fishmeal) and a wide variety of different meals have been evaluated as potential fishmeal replacers, including:

Blood meal (spray dried, IFN 5-00-381: Fowler 1990; Gallagher & Degani 1988; Langar & Metailler 1989; Luzier, Summerfelt & Ketola 1994);

Liver meal (IFN 5-00-389: Arai, 1991; Csengeri & Petitjean 1987; Dabrowski & Poczyczynski 1988; Foscarini 1988);

Meat meal (rendered, IFN 5-00-385: Langar & Metailler 1989; Shimeno et al. 1993; Watanabe & Pongmaneerat 1991; Watanabe et al. 1993);

Meat and bone meal (rendered, IFN 5-00-388: Alexis, Filioglou & Theochari 1988; Davies, Nengas & Alexis 1993; Shimeno et al. 1993, 1993a; Watanabe & Pongmaneerat 1991);

Poultry by-product meal (rendered, IFN 5-03-798: Alexis, Filioglou & Theochari 1988; Dong et al. 1993; Fowler 1991; Gallagher & Degani 1988; Gouveia 1992; Kissil 1991; Steffens 1987; Voss & Nellen 1985; Voss 1988);

Poultry feather meal (hydrolysed, IFN 5-03-795: Ajuzie & Appelbaum 1993; Fowler 1990; Hughes 1991; Langar & Metailler 1989; Shearer & Hardy 1987; Voss 1988; Wiesmann, Scheid & Pfeffer 1988); and

Miscellaneous (greavse meal - Orengo et al. 1993; chicken spleen/blood - Ajuzie & Appelbaum 1993).

Table 5 shows the reported dietary inclusion levels of the major vertebrate and invertebrate animal by-product meals. With the possible exception of liver meal and meat meal, the utilization of most vertebrate by-product meals is generally limited by specific essential amino acid (EAA) imbalances (ie. blood meal, feather meal; Table 8) and ash/mineral imbalances (ie. meat and bone meal, meat meal; Table 6) which require careful formulation so as to obtain the desired overall nutrient profile within the finished aquafeed (ie. by mixing complementary feed ingredient sources and/or by dietary supplementation with limiting essential amino acids and trace minerals; Luzier, Summerfelt & Ketola 1994).

2.2 Single-cell proteins (SCP)

Single cell protein (SCP) covers the use of unicellular and filamentous algae, fungi and bacteria in dried form as fishmeal replacers, including:

Algal SCP (*Spirulina maxima* IFN 5-19-931, *Chlorella* spp., Benemann 1992; Cysewski 1992; Gladue & Maxey 1993; Henson 1990; Nematipour, Nakagawa & Ohya 1990; Watanabe et al. 1990);

Fungal SCP (*Candida* spp., *Saccharomyces* spp. IFN 7-05-527, *Torula* spp. IFN 7-05-534, *Kluyveromyces* spp., *Phaffia* spp., Ajuzie & Appelbaum 1993; Coutteau & Lavens 1989; Dabrowski & Poczyczynski 1988; Garatun-Tjeldstoe et al. 1989; Martin, Goddard & Bemister 1993; Metailler & Huelvan 1993; Murray & Marchant 1986; Roques & Dussert 1991; Rosenlund 1986; Rumsey 1994; Rumsey, Hughes & Kinsella 1990; Sanderson & Jolly 1994; Steffens 1990); and

Bacterial SCP (*Methanobacter* spp., *Pseudomonas* spp., *Micrococcus* spp., Bayourthe 1988; Kiessling & Askbrandt 1993; Steffens et al. 1988; Voss 1988).

The most common source of SCP used within aquafeeds has been yeast SCP, either in the form of brewers/bakers yeast or commercially produced candida/torula yeast preparations (ie. 'Torprina'). Apart from being a good source of dietary protein, yeast SCP is also a rich source of vitamins (ie. B-vitamins), specific carbohydrates (ie. glucans), carotenoids (ie. astaxanthin and/or Beta-carotene depending upon the species and rearing conditions; Johnson & Hwan 1991) and exogenous enzymes. SCP holds particular promise as possible fishmeal replacers by virtue of their ability to be grown on a wide variety off substrates and waste streams (including petro-chemicals), and because of the ability to genetically modify their nutrient profile (within limits) to approximate to the dietary needs of the cultured species. However, considerable further research is required

concerning the possible reduction of the high nucleic acid content of SCP (Rumsey, Winfree & Hughes 1992), to improve nutrient availability and digestibility (ie. possibly through cell rupture), and to further improve the EAA and essential fatty acid (EFA) profile of SCP through substrate control and genetic manipulation.

2.3 Oilseeds

Plant oilseed meals are readily available in most countries and a wide variety have been evaluated as fishmeal replacers, including:

Sunflower seed meal (*Helianthus annus*, dehulled mech.extr. meal IFN 5-04-738, dehulled solv.extr. meal IFN 5-04-739, hulled mech.extr. IFN 5-09-340; Alexis, Filioglou & Theochari 1988; Atay 1989; Cardenette et al. 1993a; Martinez 1986);

Rapeseed meal (*Brassica napus, B. campestris, B. oleracea*, mech.extr. meal IFN 5-03-870, solv.extr. meal IFN 5-03-871; Abdou Dade et al. 1990; Gomes, Corraze & Kaushik 1993; McCurdy & March 1992; Prendergast et al. 1994; Shimeno et al. 1993; Teskeredzic et al. 1992; Wojno 1992);

Cottonseed meal (*Gossypium* spp., mech.extr. meal IFN 5-01-617, solv.extr. meal IFN 5-01-621, Atay 1989; Smith et al. 1988); and

Soybean meal (*Glycine max*, heat processed seeds IFN 5-04-597, protein concentrate meal IFN 5-08-038, solv.extr. meal IFN 5-20-637, mech.extr. meal IFN 5-04-600, dehulled solv.extr. meal IFN 5-04-612; Akiyama 1988, 1991; Alexis 1990; Amerio et al. 1989, 1991; Anderson et al. 1992; Arnesen et al. 1989; Dabrowski et al. 1989; Genovese et al. 1992; Kaushik 1990; Kissil 1991; Lee, Kang & Lee 1991; Lim & Akiyama 1992; Lim & Dominy 1991; Lovell 1991; Millan, Ortega & Posada 1989; Murai 1992; Olli et al. 1994; Ostrowski, Schaleger & Duerr 1992; Pongmaneerat & Watanabe 1992, 1993, 1993a; Reigh & Ellis 1992; Rumsey 1994; Rumsey, Hughes & Winfree 1993; Shimeno et al. 1992, 1993, 1993a, 1993b, 1993c; Smith et al. 1988; Van den Ingh et al. 1991; Viyakarn et al. 1992; Von der Decken & Lied 1993; Takii et al. 1989; Watanabe & Pongmaneerat 1993; Watanabe et al. 1992; 1993; Yamamoto & Akiyama 1991).

Of the different oilseeds evaluated as fishmeal replacers by far the most common has been the use of soybean meal. This has been mainly due to its ready market availability and cost, and its high nutritional value for most cultivated fish species; soybean being a good source of dietary protein and EAA, EFA (linoleic and to a lesser extent linolenic acid), and of phospholipid (ie. soy lecithin); the latter also being a rich source of choline, inositol and available phosphorus. However, like all other oilseeds and plant protein sources, soybean contains numerous endogenous anti-nutritional factors (ANF) which have to be destroyed or biologically inactivated through processing prior to being used within aquafeeds (for review see Akiyama 1991; Kaushik 1990; Krogdahl 1989; Lim & Dominy 1991; McCurdy & March 1992; Murai 1992; NRC 1993; Oliva-Teles et al. 1994; Olli, Krogdahl & Berg-Lea 1989; Pongmaneerat & Watanabe 1993, 1993a; Rumsey, Hughes & Winfree 1993; Shimeno et al. 1992a; Tacon & Jackson 1985; Viola, Arieli & Zohar 1983; Vohra & Kratzer 1991). However, the ultimate success or not of a suitably 'processed' soybean meal or oilseed meal will depend upon the ultimate blending of complementary feed ingredient sources (ie. such as the use of soybean meal together with corn gluten meal: Watanabe & Pongmaneerat, 1993) or by dietary supplementation with the limiting essential nutrients (ie. EAA: Akiyama 1988; Murai 1992; Takii et al. 1989) so as to obtain the desired final dietary nutrient profile within the manufactured aquafeed. On a cautionary note it is important to mention here the findings of the studies of Murai et al. (1989) with rainbow trout (*Oncorhynchus mykiss*) fed aquafeeds containing soybean meal supplemented with limiting crystalline amino acids. The study indicated that trout varied in their response to dietary amino acid supplementation depending upon their body size; fish with a body weight of less than 5g showing no response to dietary supplementation with EAAs, whereas 8.9g fish showed a positive response to the supplemental amino acids. Moreover, different fish species may also vary in their sensitivity to soybean quality, with rainbow trout apparently

being more tolerant of high dietary soybean inclusion levels than other salmonids or marine fish species (Reigh & Ellis 1992; Watanabe & Pongmaneerat 1993).

2.4 Grain legumes

Although not widely used as a source of dietary protein within aquafeeds (mainly due to limited availability), grain legumes which have been evaluated as potential fishmeal replacers have included:

Carob seed germ meal (*Ceratonia siliqua*, Alexis 1990);

Faba/broad bean meal (*Vicia faba*, Gouveia et al. 1993);

Pea seed meal (*Pisum sativum*, Gomes & Kaushik 1989; Gomes, Corraze & Kaushik 1993; Gouveia et al. 1993); and

Lupin seed meal (*Lupinus albus, L. angustifolius* spp. IFN 5-02-707, Gomes & Kaushik 1989; Gouveia et al. 1993; De la Higuera et al. 1988; Hughes 1988, 1991a; Moyano, Cardenette & Higuera 1992; Robaina et al. 1991).

Like the oilseeds, grain legumes may contain a wide variety of endogenous anti-nutritional factors which require deactivation and/or extraction prior to usage within aquafeeds.

2.5 Miscellaneous

Corn gluten meal (*Zea mays*, IFN 5-28-241, Alexis, Filioglou & Theochari 1988; Moyano, Cardenette & Higuera 1992; Shimeno et al. 1993, 1993a; Watanabe & Pongmaneerat 1993; Watanabe et al. 1993);

Potato protein concentrate (Moyano, Cardenette & Higuera 1992; Moyano et al. 1989; Tacon & Jackson 1985); and

Leaf protein concentrate (Johansson, Kiessling & Carlsson 1991; Rosenlund 1986).

3. FUTURE PROSPECTS AND CONCLUSION

Although a wide variety of different fishmeal replacers have been evaluated for carnivorous fish species only a few show real potential as realistic alternatives for the aquafeed compounder, namely: 1) single-cell proteins (ie. yeast and bacterial SCP; main constraints -limited availability and cost), 2) plant oilseeds & legumes (ie. soybean, rapeseed, cottonseed, sunflower seed, lupin seed, pea seed; main constraints - variable quality depending upon processing method employed and presence of ANFs, palatability), 3) terrestrial animal by-product meals (ie. liver meal, poultry by-product meal, meat meal, and to a lesser extent meat & bone meal, blood meal, hydrolysed feather meal; main constraints - limited availability, erratic quality, microbial contamination), and 4) miscellaneous plant protein sources (ie. corn gluten meal, potato protein concentrates, leaf protein concentrates; main constraints - limited availability and high cost of protein concentrates, palatability).

It follows from the above listed constraints that fishmeal replacers must be readily available in the market place in sufficient quantities throughout the year and have a constant and predictable nutritional composition if they are to realistically compete with fishmeal; one of the most important and difficult tasks of the aquafeed compounder is to produce a constant high quality fish feed for 365 days a year - one days error due to the purchase of a sub-standard batch of a major feed ingredient usually resulting in reduced fish growth and feed performance and the irreversible loss of a valuable client (ie. the fish farmer) to a competitor.

Moreover, the nutritional and economic success or not of fishmeal replacers will depend upon technical breakthroughs in feed technology and biotechnology, either through 1) the development and use of appropriate feed processing techniques for the deactivation/removal of endogenous anti-nutritional factors (Kaushik 1990; Krogdahl 1989; Rumsey, Hughes & Winfree 1993; Shimeno et al. 1992) and/or for increasing nutrient availability and digestibility (Kaushik 1990; Pongmaneerat & Watanabe 1993; Rumsey, Hughes & Kinsella 1990), 2) the use of appropriate feed formulation techniques so as to blend complementary feed ingredient sources and obtain the desired overall nutrient profile of the finished aquafeed, 3) the development and use of dietary enzyme supplements to aid digestion within the gastro-intestinal tract and so increase nutrient availability and digestibility (Carter et al. 1994; Coelho 1994; Sultana et al. 1988; Wee 1991), 4) the development and use of dietary amino acid/mineral supplements, either in crystalline/purified form or coated/protected/conjugated form, to overcome inherent amino acid and/or mineral imbalances (Luzier, Summerfelt & Ketola 1994; Murai 1992), 5) the development and use of dietary feeding stimulants so as to enhance feed palatability and maximize feed intake (Holm & Walther 1988; Hughes 1991a; Nakajima, Uchida & Ishida 1990; Pacolet, Reynders & Ollevier 1991; Reigh & Ellis 1992; Ward 1991), 6) the development and use of genetic manipulation techniques to produce single-cell proteins with the desired dietary nutrient profiles, and 7) the use of plant breeding programmes to produce genetically selected varieties low in specific anti-nutritional factors or high in specific essential nutrients (Prendergast et al. 1994).

Although fish meal will almost certainly remain as the main source of dietary protein within aquafeeds for carnivorous fish species for the rest of the decade, it is believed that SCP and plant protein concentrates/oilseeds will gain greater usage and eventually reduce dietary fishmeal levels to about half their current level (Tacon 1994). Although this shift is expected to be a slow process, this change may become more rapid should fishmeal prices increase (due to the increased competition for fishmeal or reduced fishmeal production), the market value of the cultured species stabilize or decline (due to over production of the target species and market saturation), or should government legislatures impose limits on the phosphorus or fishmeal content of aquafeeds (ie. by reducing the usage of fishmeals with a high phosphorus content; Tacon, Phillips & Barg 1994).

On a concluding note, if fish farming is to play a major role as a food production system then it is imperative that the fish species chosen for mass production have herbivorous or omnivorous feeding habits and so are not dependent upon the use of non-sustainable 'food grade' protein-rich feed inputs such as fishmeal! For example, with the exception of mink and crocodile farms, all land-based animal farming systems are based on the culture of omnivorous or herbivorous (ruminant) animal species, including poultry, ducks, pigs, sheep, rabbits, goats, beef and dairy cattle. The important lesson to learn from developing countries (who currently produce over 70% of total world finfish production) is that their farming systems are based on the polyculture of complementary herbivorous/omnivorous fish species, require only fertilizer and/or low-protein supplementary feed inputs, are net fish protein producing systems (rather than net fish protein reducing systems) and are more energy efficient than their counterpart farming systems in developed countries; the real value of the farmed fish within developing countries not being its modest final retail price but rather its high nutritional value as a much needed source of inexpensive animal protein in the diet of 'mankind'.

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TABLE 1. CONTRIBUTION OF AQUACULTURE TO WORLD FISHERY PRODUCTION 1/

AQUACULTURE CONTRIBUTION TO WORLD FISHERY PRODUCTION 1986-1992
(values given in '000 mt)

	1986	1987	1988	1989	1990	1991	1992
WORLD CATCH AND CULTURE OF FISH AND SHELLFISH	92,845	94,402	99,086	100,311	97,556	97,052	98,113
TOTAL CATCH	84,038	84,252	87,876	88,814	85,435	84,271	84,192
TOTAL CULTURED	8,807	10,150	11,210	11,497	12,121	12,781	13,921
- % total	9.5%	10.7%	11.3%	11.5%	12.4%	13.2%	14.2%
Total fish landings	81,750	81,978	86,271	87,047	84,576	83,387	83,270
Capture	75,766	75,116	78,699	79,260	76,219	74,619	73,853
Culture	5,984	6,862	7,572	7,787	8,357	8,768	9,417
- % total	7.3%	8.4%	8.8%	8.9%	9.9%	10.5%	11.3%
Freshwater fishes	9,675	10,416	11,080	11,439	12,174	12,285	13,071
- Capture	4,620	4,588	4,667	4,867	5,234	5,014	5,090
- Culture	5,055	5,828	6,413	6,572	6,940	7,271	7,981
- % total	52.2%	56.0%	57.9%	57.5%	57.0%	59.2%	61.0%
Diadromous fishes	2,538	2,678	2,680	3,053	3,154	3,271	3,002
- Capture	1,843	1,907	1,809	2,122	2,048	2,118	1,921
- Culture	695	771	871	931	1,106	1,153	1,081
- % total	27.4%	28.8%	32.5%	30.5%	35.1%	35.2%	36.0%
Marine fishes	69,537	68,884	72,511	72,555	69,248	67,831	67,197
- Capture	69,303	68,621	72,223	72,271	68,937	67,487	66,842
- Culture	234	263	288	284	311	344	355
- % total	0.3%	0.4%	0.4%	0.4%	0.4%	0.5%	0.5%
Total crustacean landings	4,117	4,342	4,564	4,725	4,798	5,138	5,395
Capture	3,729	3,753	3,910	4,022	4,048	4,225	4,413
Culture	388	589	654	703	750	913	982
- % total	9.4%	13.6%	14.3%	14.9%	15.6%	17.8%	18.2%
Shrimps, prawns	2,240	2,380	2,515	2,526	2,601	2,808	2,912
- Capture	1,927	1,880	1,939	1,907	1,943	1,993	2,028
- Culture	313	500	576	619	658	815	884
- % total	14.0%	21.0%	22.9%	24.5%	25.3%	29.0%	30.3%
Freshwater spp.	214	247	231	252	251	270	289
- Capture	156	177	172	192	185	202	227
- Culture	58	70	59	60	66	68	62
- % total	27.1%	28.3%	25.5%	23.8%	26.2%	25.2%	21.5%
Total mollusc landings	6,627	7,718	7,967	8,225	7,899	8,150	8,885
Capture	4,222	5,046	5,016	5,267	4,926	5,075	5,385
Culture	2,405	2,672	2,951	2,958	2,973	3,075	3,500
- % total	36.3%	34.6%	37.0%	36.0%	37.6%	37.7%	39.3%
Miscellan. aquatic animals	351	364	284	314	283	377	563
Capture	321	337	251	265	242	352	541
Culture	30	27	33	49	41	25	22
- % total	8.5%	7.4%	11.6%	15.6%	14.5%	6.6%	3.9%
AQUATIC PLANTS - LANDINGS	3,863	3,553	4,100	4,347	4,302	4,877	6,179
Capture	462	529	750	931	1,031	753	789
Culture	3,401	3,024	3,350	3,416	3,271	4,124	5,390
- % total	88.0%	85.1%	81.7%	78.6%	76.0%	84.5%	87.2%

1/ FAO/FIDI (1994, 1994a)

Mean increase in production of total cultured 1) fish and shellfish, 2) fish, 3) freshwater fishes, 4) diadromous fishes, 5) marine fishes, 6) crustaceans, 7) shrimps, and 8) freshwater crustaceans from 1991 to 1992, and from 1986 to 1992 was 1) 8.9 and 9.7%, 2) 7.4 and 9.6%, 3) 9.8 and 9.7%, 4) -6.2 and 9.3%, 5) 3.2 and 8.6%, 6) 7.6 and 25.5%, 7) 8.5 and 30.4%, and 8) -8.8 and 1.1%, respectively.

TABLE 2. 1992 FINFISH & CRUSTACEAN AQUACULTURE PRODUCTION BY SPECIES GROUPS[1/]

FRESHWATER FISHES	**7,980,737 (mt)**
Carps, barbels & other cyprinids	
Silver carp (Hypophthalmichthys molitrix)	1,616,613
Grass carp (Ctenopharyngodon idella)	1,252,728
Common carp (Cyprinus carpio)	1,022,887
Bighead carp (Hypophthalmichthys nobilis)	786,604
Cyprinids (species not given)	419,185
Roho labeo (Labeo rohita)	309,020
Catla (Catla catla)	301,806
Mrigal carp (Cirrhinus mrigala)	295,551
Crucian carp (Carassius carassius)	257,198
White amur bream (Parabramis pekinensis)	181,516
Mud carp (Cirrhinus mulitorella)	81,050
Black carp (Mylopharyngodon piceus)	52,287
Java barb (Puntius javanicus)	23,000
Thai silver barb (Puntius gonionotus)	19,955
Nilem carp (Osteochilus hasselti)	9,870
Hovens carp (Leptobarbus hoeveni)	9,413
Golden shiner (Notemigonus crysoleucas)	9,352
Roaches (Rutilus spp)	2,501
Tench (Tinca tinca)	796
Goldfish (Carassius auratus)	549
Pond loach (Misgurnus anguillicaudatus)	324
Asian barbs (Puntius spp)	100
Group total	**6,652,305 (83.3%)**
Tilapia & other cichlids	
Nile tilapia (Oreochromis niloticus)	302,674
Tilapia spp. (species not given)	106,987
Mozambique tilapia (Oreochromis mossambica)	45,314
Blue tilapia (Oreochromis aureus)	16,990
Three spotted tilapia (O. andersonii)	1,000
Cichlids (Cichlidae; spp not given)	400
Cichla (Cichla ocellaris)	80
Cichlasoma (Cichlasoma maculicaudum)	16
Cichlasoma (Cichlasoma managuensis)	10
Redbreast tilapia (Tilapia rendalli)	3
Aequidens (Aequidens rivulatus)	2
Tilapia (Oreochromis spilurus)	1
Group total	**473,477 (5.9%)**
Miscellaneous freshwater fishes	
Freshwater fishes (species not given)	449,765
Channel catfish (Ictalurus punctatus)	211,067
Torpedo-shaped catfishes (Clarias spp)	83,325
Climbing perch (Anabas testudineus)	51,073
Snakeskin gourami (Trichogaster pectoralis)	14,220
Pangas catfish (Pangasius pangasius)	13,220
Striped snakehead (Channa striatus)	5,040
North African catfish (Clarias gariepinus)	5,038
Kissing gourami (Helostoma temmincki)	4,900
Giant gourami (Osphronemus goramy)	3,850
Colossoma (Colossoma brachypomum)	2,100
Black bullhead (Ictalurus melas)	1,766
Indonesian snakehead (Channa micropeltes)	1,490
Philippine catfish (Clarias batrachus)	1,198
Snakeheads (= Murruls; Channa spp)	1,100

Table 2. Continuation

Catfish (Chrysichthys nigrodigitatus)	1,042
Northern pike (Esox lucius)	764
Pike-perch (Stizostedion lucioperca)	602
Dormitator (Dormitator latifrons)	597
Snakehead (Channa argus)	500
Catfish (Clarias anguillaris)	393
Colossoma (Colossoma macropomum)	358
Freshwater gobies (Gobiidae)	330
Heterotis (Heterotis spp)	303
Wels catfish (Silurus glanis)	202
Freshwater siluroids (Siluroidei)	195
Other gouramis (Trichogaster spp)	190
Hong Kong catfish (Clarias fuscus)	110
Upsidedown catfishes (Synodontis spp)	80
Black catfishes (Chrysichthys spp)	50
Silver perch (Bidyanus bidyanus)	20
Colossoma (Colossoma bidens)	20
Prochilodus (Prochilodus reticulatus)	10
Knife fishes (Notopterus spp)	10
Arapaimagiyas spp	10
Characins (Characidae)	10
Buffalo fishes (Ictiobus spp)	7
Group total	**854,955 (10.7%)**
DIADROMOUS FISHES	1,080,698
Sturgeons, paddlefishes	
Sturgeons (Acipenseridae)	437
Group total	**437 (0.04%)**
River eels	
Japanese eel (Anguilla japonica)	55,743
Anguilla spp. (species not given)	36,949
European eel (Anguilla anguilla)	6,976
Group total	**99,668 (9.2%)**
Salmons, trouts, smelts	
Rainbow trout (Oncorhynchus mykiss)	296,571
Atlantic salmon (Salmo salar)	241,727
Coho salmon (Oncorhynchus kisutch)	48,379
Trouts (species not given)	15,589
Ayu sweetfish (Plecoglossus altivelis)	12,833
Chinook salmon (Oncorhynchus tshawytscha)	8,881
Salmonoids (Salmonoidei; spp not given)	2,000
Whitefishes (Coregonus spp)	633
Sea trout (Salmo trutta)	617
Arctic char (Salvelinus alpinus)	531
Brook trout (Salvelinus fontinalis)	306
Pacific salmon (Oncorhynchus spp.)	200
Other chars (Salvelinus spp)	73
Masu salmon (Oncorhynchus masou)	68
Sockeye salmon (Oncorhynchus nerka)	10
Group total	**628,418 (58.1%)**
Miscellaneous diadromous fishes	
Milkfish (Chanos)	339,289
Giant sea perch (Lates calcarifer)	12,886
Group total	**352,175 (32.6%)**

Table 2. Continuation

MARINE FISHES	**355,718**
Flounders, halibuts, soles	
Bastard halibut (Paralichthys olivaceus)	10,327
Turbot (Psetta maxima)	1,733
Common sole (Solea vulgaris)	15
Group total	**12,075 (3.4%)**
Cods, hakes, haddocks	
Atlantic cod (Gadus morhua)	28
Group total	**28 (0.01%)**
Redfishes, basses, congers	
Japanese seabream (Sparus (=Pagrus) major)	65,950
Gilthead seabream (Sparus auratus)	13,414
Seabass (Dicentrarchus labrax)	5,312
Puffers (Tetraodontidae; spp not given)	4,068
Groupers/seabasses (Serranidae;sp not given)	1,474
Goldlined seabream (Rhabdosargus sarba)	1,253
Snappers (Lutjanidae spp)	947
Groupers (Epinephelus spp)	899
Dark seabream Acanthopagrus macrocephalus)	896
Porgies/seabreams (Sparidae; spp not given)	412
Seabasses (Dicentrarchus spp)	400
Marble goby (Oxyeleotris marmorada)	175
Sargo breams (Diplodus spp)	136
Crimson seabream (Evynnis japonica)	117
Silver seabream (Chrysophrys major)	117
White seabream (Diplodus sargus)	100
Filefishes (Cantherines (=Navodon) spp)	99
Plectropomus (Plectropomus maculatus)	67
Greasy grouper (Epinephelus tauvina)	45
Red drum (Sciaenops ocellatus)	15
Golden perch (Macquaria ambigua)	11
Murray perch (Maccullochella peeli)	11
Hong kong grouper (Epinephelus akaara)	10
Scats (Scatophagus spp)	10
Snappers/jobfishes (Lutjanidae;sp not given)	4
White-spotted spinefoot (Siganus canaliculatus)	2
Group total	**95,944 (27.0%)**
Jacks, mullets, sauries	
Japanese amberjack (Seriola quinqueradiata)	148,988
Grey mullet (Mugil cephalus)	11,800
Mullets (Mugilidae; species not given)	9,568
Japanese jack mackerel (Trachurus japonicus)	7,161
Jack/horse mackerels (Trachurus spp)	1,853
Greater amberjack (Seriola dumerili)	31
Bluefish (Pomatomus saltatrix)	29
Group total	**179,430 (50.4%)**
Tunas, bonitos, billfishes	
Northern bluefin tuna (Thunnus thynnus)	123
Group total	**123 (0.03%)**
Miscellaneous marine fishes	
Osteichthyes (species not given)	68,118
Group total	**68,118 (19.1%)**

Table 2. Continuation

CRUSTACEANS	**981,978**
Freshwater crustaceans	
Red swamp crawfish (Procambarus clarkii)	30,991
Giant river prawn Macrobrachium rosenbergii)	19,215
Other freshwater crustacea (spp not given)	12,021
Yabby crayfish (Cherax destructor)	114
Red claw crayfish (Cherax quadricarinatus)	40
Other crayfishes (Astacus sp, Cambarus spp)	35
Marron crayfish (Cherax tenuimanus)	17
Group total	**62,433 (6.4%)**
Sea-spiders, crabs	
Chinese river crab (Eriocheir sinensis)	9,509
Mud crab (Scylla serrata)	3,728
Other marine crabs (Reptantia; sp not given)	231
Swimcrabs (Portunus spp)	225
Group total	**13,693 (1.4%)**
Lobsters, spiny-rock lobsters	
Palinurid spiny lobsters (Palinurus spp)	62
Other tropical spiny lobsters (Panulirus spp)	41
Longlegged spiny lobster (Panulirus longipes)	21
Group total	**124 (0.01%)**
Shrimps, prawns	
Giant tiger prawn (Penaeus monodon)	388,565
Fleshy prawn (Penaeus chinensis)	207,428
Whiteleg shrimp (Penaeus vannamei)	111,075
Natantian decapods (Natantia)	56,321
Penaeid shrimp (Penaeus spp, spp not given)	41,994
Banana prawn (Penaeus merguiensis)	28,890
Metapenaeid shrimp (Metapenaeus spp)	23,537
Blue shrimp (Penaeus stylirostris)	12,864
Kuruma prawn (Penaeus japonicus)	7,744
Akiami paste shrimp (Acetes japonicus)	3,000
Indian white prawn (Penaeus indicus)	1,640
Redtail prawn (Penaeus penicillatus)	907
Common prawn (Palaemon serratus)	60
Atlantic seabob (Xiphopenaeus kroyeri)	50
Group total	**884,075 (90.0%)**
Miscellaneous marine crustaceans	
Marine crustacea (species not given)	21,649
Brine shrimp (Artemia salina)	4
Group total	**21,653 (2.2%)**

1/ FAO/FIDI (1994)

Carnivorous fish species constitute 0.7% of freshwater fish production (56,743 mt; including black carp, snakeheads, pike & pike-perch), 68.6% of diadromous fish production (740,972 mt; all species excluding milkfish & sturgeon), and 94.0% of marine fish production (334,348 mt; all species excluding mullets and rabbitfish).

TABLE 3. UTILIZATION OF WORLD FISHERY RESOURCES 1/

UTILIZATION OF WORLD FISHERY RESOURCES AND FISHMEAL PRODUCTION 1986-1992 (values given in '000 mt)							
	1986	1987	1988	1989	1990	1991	1992
TOTAL WORLD LANDINGS 1/	92,845	94,402	99,086	100,311	97,556	97,052	98,113
- For human consumption	63,613	66,307	69,373	70,547	69,864	68,950	71,409
- % total landings	68.5%	70.2%	70.0%	70.3%	71.6%	71.0%	72.8%
- For other purposes	29,232	28,095	29,713	29,764	27,692	28,102	26,704
Reduction 2/	27,432	26,495	27,913	28,064	26,092	26,452	24,904
- % total landings	29.5%	28.1%	28.2%	28.0%	26.7%	27.3%	25.4%
- % total catch	32.3%	31.1%	31.4%	31.2%	30.4%	31.1%	29.6%
Miscellan. purposes	1,800	1,600	1,800	1,700	1,600	1,650	1,800
Total fishmeal production 2/	6,693	6,489	6,845	6,876	6,370	6,384	6,002
- Fishmeal from white-fish	373	373	385	367	318	309	303
- % total fishmeal	5.6%	5.7%	5.6%	5.3%	5.0%	4.8%	5.0%
Hake meal	4.4	23.1	40.2	41.9	21.5	27.1	35.6
Other white-fish	369	350	345	325	297	281	267
- Fishmeal from oily fish	6,092	5,870	6,187	6,235	5,820	5,915	5,559
- % total fishmeal	91.0%	90.5%	90.4%	90.7%	91.4%	92.7%	92.6%
Anchoveta meal	745	499	648	835	593	725	797
Jack mackerel meal	279	437	496	542	563	679	670
Pilchard meal	895	782	505	528	362	358	271
Menhaden meal	269	303	229	210	203	211	176
Capelin meal	158	127	162	112	119	56	157
Tuna meal	41.5	54.2	53.3	48.5	41.7	40.4	41.2
Herring meal	26.1	30.1	40.0	36.3	42.7	39.8	36.2
Clupeoid fish meal	59.6	67.1	66.2	87.2	89.3	109.8	93.8
Oily-fish meal (others)	3,618	3,569	3,989	3,835	3,806	3,696	3,316
- Miscellaneous meals 3/	39.7	45.1	50.7	50.6	37.3	30.4	31.4
- % total fishmeal	0.6%	0.7%	0.7%	0.7%	0.6%	0.5%	0.5%
- Fish solubles	189	201	222	224	195	130	110
- % total fishmeal	2.8%	3.1%	3.2%	3.3%	3.1%	2.0%	1.8%
Total fishmeal exports	3,265	3,283	3,214	3,753	3,187	3,292	3,297
- Value 1,000,000 US $	1,109	1,228	1,601	1,639	1,330	1,541	1,680
Total oil & fat production 4	1,671	1,453	1,556	1,633	1,411	1,374	1,024
- Fish liver oils	24.6	34.0	39.7	31.5	24.3	24.0	17.4
- Fish oils & fats (other)	1,646	1,419	1,516	1,602	1,387	1,350	1,006
Total oil & fat exports	793	686	836	792	736	665	540
- Value 1,000,000 US $	202	181	292	194	206	236	243

1/ Total world landings includes fish and shellfish, and excludes whales, seals, other aquatic mammals and aquatic plants (FAO/FIDI, 1994a, 1994b)
2/ Only whole fish destined for the manufacture of oils and meals is included.
3/ Miscellaneous meals of aquatic origin include crab meal, shrimp meal and crustacean meals
4/ Oils and fats, crude or refined, of aquatic animal origin

TABLE 4. PRODUCTION OF MAJOR CULTURED FISH AND CRUSTACEAN SPECIES 1986-1992 1/

1986-1992 TOP 20 AQUACULTURE PRODUCERS - FISH AND CRUSTACEANS									
PRODUCTION (1,000 t)	1986	1987	1988	1989	1990	1991	1992	% Inc 91-92	% Inc 86-92
1. Silver carp	1,275	1,429	1,598	1,445	1,495	1,462	1,617	10.6	4.5
2. Grass carp	440	542	606	954	1,047	1,063	1,253	17.9	30.8
3. Common carp	802	1,015	1,093	982	1,108	1,176	1,023	-13.0	4.6
4. Bighead carp	607	642	718	643	671	694	787	13.4	4.9
5. Giant tiger prawn**	89	148	160	209	234	312	389	24.7	56.2
6. Milkfish	311	332	346	334	434	417	339	-18.7	1.5
7. Roho labeo	164	189	216	243	243	293	309	5.5	14.7
8. Nile tilapia	111	124	133	204	225	257	303	17.9	28.8
9. Catla	155	181	207	233	234	290	302	4.1	15.8
10 Rainbow trout*	204	228	245	253	276	281	297	5.7	7.6
11. Mrigal carp	106	123	141	158	159	188	296	57.4	29.9
12. Crucian carp	93	109	122	209	216	222	257	15.8	29.4
13. Atlantic salmon*	60	68	112	166	190	230	242	5.2	50.5
14. Channel catfish	149	170	165	184	165	179	211	17.9	6.9
15. Fleshy prawn**	83	153	200	186	185	220	207	-5.9	24.9
16. White amur bream	148	174	195	144	162	153	182	18.9	3.8
17. Yellowtail*	149	160	167	155	162	162	149	-8.0	0
18. Whiteleg shrimp**	35	72	75	72	76	105	111	5.7	36.2
19. Mud carp	57	70	78	78	80	80	81	1.2	7.0
20. Japanese seabream*	33	38	45	46	52	60	66	10.0	16.7
Total top 20	5,071	5,967	6,622	6,898	7,414	7,844	8,421	7.4	11.0
Total world	6,372	7,451	8,226	8,491	9,107	9,681	10,399	7.4	10.4
% world total	79.6	80.1	80.5	81.2	81.4	81.0	81.0		

1/ Source: FAO/FIDI (1994)

*/ Carnivorous fish species; **/ Omnivorous scavengers or detritus feeders with some spp (#5) being more carnivorous than others

%/Inc Average increase in production from 1991 to 1992 and from 1986 to 1992; the later calculated as [(1992-1986)/6]*100

Mean accumulated increase in production of carnivorous fish spp from 1991-1992 & 1986-1992 was 2.9% & 11.5% respectively

Mean accumulated increase in production of non-carnivorous fish spp from 1991-1992 & 1986-1992 was 7.5% & 9.6% respectively

Mean accumulated increase in production of marine shrimp spp from 1991-1992 & 1986-1992 was 11.0% & 40.3% respectively

Table 5. Observed dietary inclusion level (%) of different fishmeal replacers within practical aquafeeds for carnivorous fish, and suggestions for their maximum dietary usage *

Feed ingredient	Observed range	Usual level	Maximum
Algal SCP - Spirulina 5-19-931	1 - 10	1	10
Bacterial SCP - Methanobacteria	5 - 70	15	35
Blood meal 5-00-381	2 - 30	4	20
Corn gluten meal 5-28-241	4 - 20	10	25
Cottonseed meal 5-01-617/621	10 - 60	15	35
Earthworm (E. foetida) meal	5 - 40	15	35
Feather meal 5-03-795	3 - 55	6	20
Liver meal 5-00-389	5 - 65	10	50
Lupin seed meal 5-02-707	10 - 44	10	35
Meat meal 5-00-385	10 - 70	15	50
Meat & bone meal 5-00-388	5 - 78	10	35
Pea seed meal 5-03-600	10 - 38	10	35
Potato protein concentrate	5 - 30	6	35
Poultry byprod.meal 5-03-798	10 - 70	15	35
Poultry feather meal 5-03-795	5 - 30	6	20
Rapeseed meal 5-03-870/871	10 - 60	15	35
Silkworm pupa 5-11-787	10 - 50	15	35
Soybean meal 5-20-637	6 - 60	15	35
Soybean (full fat) 5-04-597	10 - 70	15	35
Soybean protein conc. 5-08-038	10 - 30	10	35
Sunflower seed meal 5-04-738/739	10 - 60	10	35
Yeast 7-05-527/534	2 - 62	10	50

* Modified from Tacon (1993)

Table 6. Average proximate composition of fishmeal replacers used within aquafeeds for carnivorous fish species (all values are expressed as % by weight on a as-fed basis: Water-H_20; Crude Protein - CP; Lipid or Ether Extract - EE; Crude Fibre - CF; Ash; Calcium -Ca; Phosphorus - P[1/]

INGREDIENT NAME	IFN	H_20	CP	CF	EE	Ash	Ca	P
Algae, Spirulina spp, meal *	5-19-931	6.7	58.6	0.5	4.8	6.7	-	-
Bacterial (Pseudomonas/Methylophilus) SCP *		6.4	73.1	0.4	5.7	11.7	0.54	2.33
Blood meal	5-00-380	8.0	79.8	1.0	1.3	5.3	0.29	0.24
Blood meal, spray dehyd	5-00-381	7.0	85.6	1.0	1.3	6.6	0.30	0.23
Corn gluten meal	5-28-241	9.0	42.7	4.4	2.2	3.1	0.15	0.45
Cotton seed meal, mech extd	5-01-617	7.0	41.0	11.9	4.6	6.1	0.19	1.08
Cotton seed meal, solv extd	5-01-621	9.0	41.2	12.1	1.4	6.5	0.17	1.10
Earthworm (Eisenia foetida) meal *		7.4	56.4	1.6	7.8	8.8	0.48	0.87
Faba/broad bean meal *		11.7	29.2	0.8	1.9	2.6	-	-
Leaf (rye grass) protein concentrate, dried *		5.4	57.7	1.7	20.6	3.7	0.27	0.35
Liver meal	5-00-389	8.0	66.0	1.4	15.7	6.3	0.56	1.26
Lupin seed meal *	5-02-707	11.5	40.0	12.1	6.4	4.1	0.26	0.42
Meat meal, rend	5-00-385	6.0	51.4	2.7	9.1	27.0	8.85	4.44
Meat & bone meal, rend	5-00-388	7.0	50.4	2.2	9.7	29.3	10.30	5.10
Pea seed	5-03-600	11.0	22.5	6.1	1.2	3.0	0.14	0.39
Peanut meal, mech extd	5-03-649	7.0	48.1	6.9	5.8	5.1	0.19	0.57
Peanut meal, solv extd	5-03-650	8.0	48.1	9.9	1.3	5.8	0.27	0.62
Potato protein concentrate *		8.5	78.1	0.1	0.4	1.3	0.07	0.25
Poultry by-product meal, rend	5-03-798	7.0	58.7	2.3	13.1	15.7	3.51	1.83
Poultry feathers, hydrolyzed	5-03-795	7.0	84.9	1.4	2.9	3.5	0.26	0.67

INGREDIENT NAME	IFN	H_2O	CP	CF	EE	Ash	Ca	P
Rape seed meal, mech extd	5-03-870	8.0	35.6	12.0	7.3	6.9	0.66	1.04
Rape seed meal, solv extd	5-03-871	9.0	37.0	12.0	1.7	6.8	0.61	0.95
Silkworm pupa, dehyd	5-11-787	6.0	56.6	8.6	12.3	4.0	-	-
Soybean protein concentrate	5-08-038	8.0	84.3	0.1	0.5	3.5	0.11	0.68
Soybean seeds, heat processed	5-04-597	10.0	38.0	5.0	18.0	4.6	0.25	0.59
Soybean seeds, mech extd	5-04-600	10.0	42.9	5.9	4.8	6.0	0.26	0.61
Soybean seeds, solv extd	5-20-637	11.0	44.6	6.2	1.4	6.5	-	-
Soybean seeds, dehulled, solv extd	5-04-612	10.0	49.7	3.4	0.9	5.8	0.26	0.63
Sunflower seed meal, solv extd	5-09-340	10	23.3	31.6	1.1	5.6	0.21	0.93
Sunflower seed, dehulled, mech extd	5-04-738	7.0	41.4	12.2	8.0	6.6	0.39	1.06
Sunflower seed, dehulled, solv extd	5-04-739	7.0	46.3	11.4	2.9	7.6	0.41	0.91
Yeast, brewers, dehyd	7-05-527	7.0	43.8	2.9	0.8	6.6	0.12	1.40
Yeast, torula, dehyd	7-05-534	7.0	49.1	2.3	1.6	7.7	0.50	1.59

1/ All data taken from the United States - Canadian Tables of Feed Composition (NRC, 1982)

*/ Tacon (1987)

Table 7. Average essential amino acid (EAA) composition of fishmeal replacers commonly used within aquafeeds for carnivorous fish species (all values are expressed as % by weight on a as-fed basis: Arginine -Arg; Cystine -Cys; Methionine -Met; Threonine -Thr; Isoleucine -Iso; Leucine -Leu; Lysine -Lys; Valine -Val; Tyrosine -Tyr; Tryptophan -Try; Phenylalanine -Phe; Histidine -His)[1/]

Feed # (IFN)	Arg	His	Iso	Leu	Lys	Met	Cys	Phe	Tyr	Thr	Try	Val
5-19-931 *	3.93	1.09	3.63	4.84	2.79	0.85	0.24	3.02	2.42	2.79	0.85	3.93
Bacterial SCP *	3.67	1.50	3.34	5.43	4.30	1.75	0.41	3.07	2.70	3.29	0.80	4.16
5-00-380	3.25	3.97	0.87	9.94	6.33	0.88	1.24	5.49	1.92	3.56	0.98	6.52
5-00-381	3.60	5.20	0.91	11.03	7.48	0.88	0.72	5.92	2.27	3.65	1.05	7.56
5-28-241	1.39	0.97	2.25	7.22	0.80	1.04	0.67	2.78	1.01	1.42	0.21	2.19
5-01-617	4.18	1.07	1.45	2.32	1.60	0.58	0.73	2.18	0.94	1.34	0.53	1.90
5-01-621	4.21	1.11	1.52	2.33	1.69	0.59	0.77	2.24	1.03	1.38	0.56	1.88
Earthworm meal *	2.73	1.44	2.01	4.03	3.17	1.36	0.34	1.93	1.68	2.72	0.35	2.26
Faba bean meal *	2.08	0.58	0.96	1.63	1.51	0.21	0.16	1.00	0.82	0.89	0.22	1.13
Leaf-protein con *	3.75	1.32	2.88	5.48	3.81	1.04	0.52	3.63	2.37	2.88	0.86	3.75
5-02-707	2.96	0.81	1.37	2.24	1.65	0.24	0.43	1.15	1.10	1.14	0.31	1.26
5-00-389	4.04	1.48	3.10	5.31	5.21	1.22	0.94	2.92	1.70	2.49	0.69	4.14
5-00-385	3.60	0.96	1.75	3.19	3.23	0.70	0.65	1.81	0.96	1.64	0.34	2.52
5-00-388	3.49	0.96	1.64	3.06	2.90	0.65	0.50	1.70	0.79	1.65	0.30	2.45
5-03-600	1.39	0.65	1.14	1.78	1.54	0.28	0.19	1.25	-	0.93	0.22	1.25
5-03-649	5.06	1.08	1.69	3.02	1.50	0.49	0.75	2.34	1.66	1.24	0.47	2.08
5-03-650	4.55	0.95	1.76	2.70	1.77	0.42	0.73	2.04	1.51	1.16	0.48	1.88
Potato-protein *	3.70	1.40	4.70	7.60	6.00	2.10	1.40	5.00	4.80	4.20	0.95	4.50
5-03-798	3.77	1.01	2.38	4.00	2.89	1.06	0.92	1.84	0.94	1.94	0.46	2.86

Feed # (IFN)	Arg	His	Iso	Leu	Lys	Met	Cys	Phe	Tyr	Thr	Try	Val
5-03-795	7.05	0.99	4.06	6.94	2.32	0.55	3.24	3.05	2.32	3.97	0.52	6.48
5-03-870	1.99	0.90	1.41	2.41	1.67	0.68	0.30	1.42	0.85	1.53	0.48	1.81
5-03-871	2.06	0.99	1.35	2.50	1.98	0.71	0.30	1.41	0.79	1.56	0.43	1.79
5-08-038	7.34	2.41	4.60	6.33	5.61	0.88	0.92	4.33	3.10	3.34	0.88	4.38
5-04-597	2.80	1.01	2.18	2.57	2.40	0.54	0.55	2.10	1.22	1.69	0.52	2.02
5-04-600	3.07	1.14	2.63	3.62	2.79	0.65	0.56	2.20	1.55	1.72	0.61	2.28
5-04-612	3.67	1.22	2.46	3.73	3.17	0.71	0.75	2.44	1.68	1.94	0.69	2.55
5-09-340	2.30	0.55	1.00	1.60	1.00	0.50	0.50	1.15	-	1.05	0.45	1.60
5-04-738	3.45	0.90	1.76	2.47	1.61	0.94	0.69	1.80	1.00	1.37	0.50	2.01
5-04-739	4.42	1.23	2.25	3.83	1.92	1.16	0.74	2.36	1.39	1.93	0.61	2.60
7-05-527	2.20	1.09	2.21	3.23	3.11	0.74	0.49	1.83	1.50	2.12	0.52	2.36
7-05-534	2.64	1.32	2.85	3.52	3.74	0.77	0.61	2.85	2.00	2.64	0.52	2.96

1/ All data taken from the United States - Canadian Tables of Feed composition (NRC, 1982)

* Data from Tacon (1987)

Table 8. Chemical score and limiting essential amino acids of different protein sources 1/2/

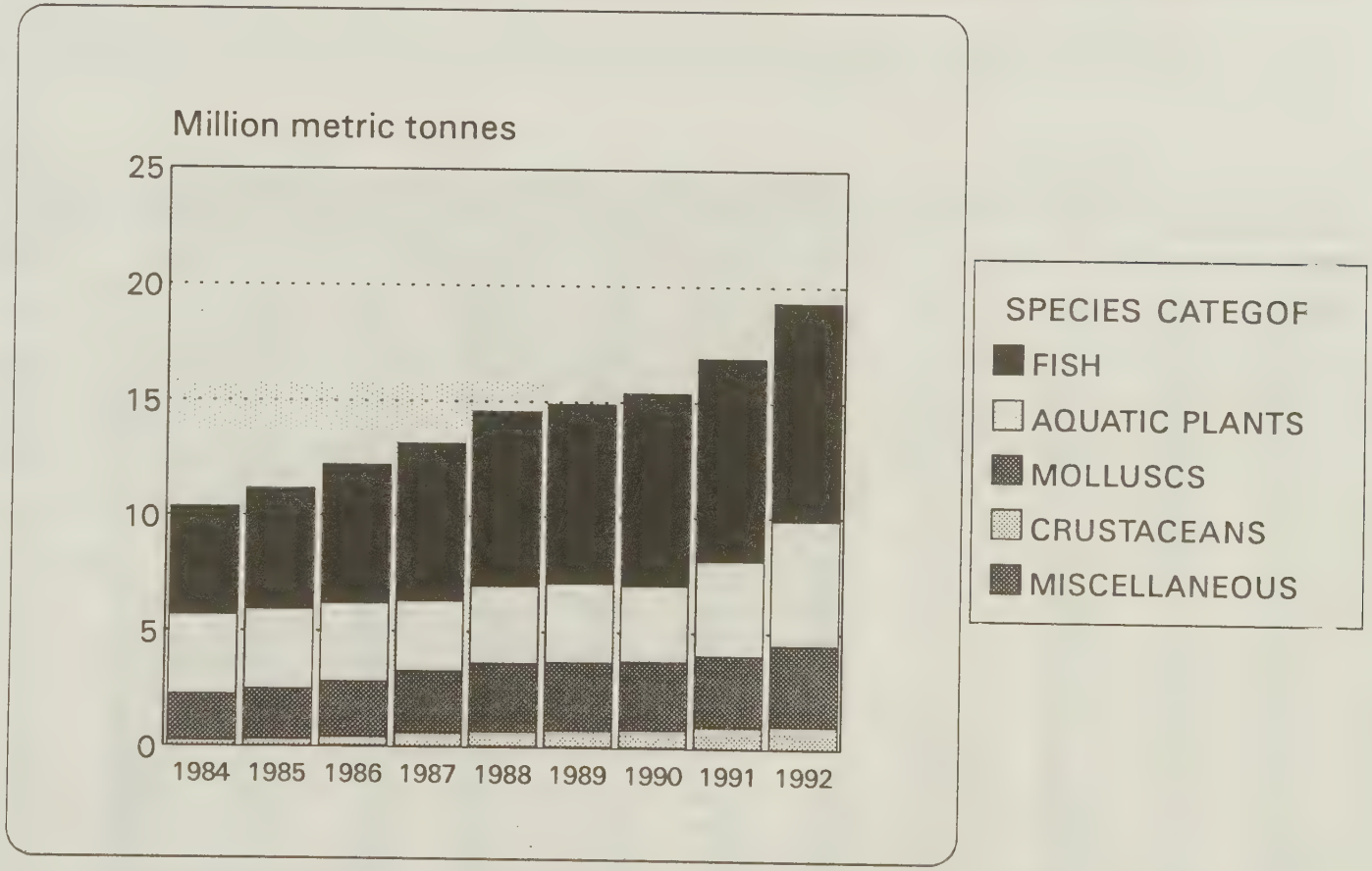
Feedstuff	THR	VAL	MET	CYS	ISO	LEU	PHE	TYR	LYS	HIS	ARG	TRY	LAA 3/
Yellow lupin	**66**	81	**20**	126	117	125	85	94	**64**	117	192	135	Met
Haricot bean	80	103	**43**	**67**	120	121	118	83	92	127	104	129	Met
Cottonseed	**65**	102	**52**	118	92	94	122	89	**52**	117	205	141	Lys
Sunflower	**65**	124	83	137	115	104	109	91	**42**	119	159	165	Lys
Sesame	**58**	98	109	148	91	105	86	114	**33**	114	211	153	Lys
Coconut	**65**	114	**61**	96	115	112	95	92	**37**	81	217	123	Lys
Groundnut	**55**	99	**39**	133	117	100	107	117	**53**	100	196	141	Met
Rapeseed	93	118	83	70	113	116	94	77	74	131	112	159	Cys
Soybean	74	101	**46**	130	128	115	105	97	76	106	123	176	Met
Corn gluten meal	61	105	88	113	137	244	133	71	**22**	92	55	56	Lys
Pea seed	83	124	**49**	66	143	124	124	-	86	127	113	122	Met
Potato protein	89	125	**63**	96	128	120	112	149	74	73	73	118	Met
Leaf protein	84	127	**57**	**56**	112	120	122	129	71	90	96	141	Cys
Algal SCP (Spirulina)	87	136	**52**	**30**	159	118	105	123	**55**	75	111	165	Cys
Yeast SCP (Bakers)	93	116	**63**	85	139	112	91	108	86	106	89	141	Met
Yeast SCP (Torula)	94	118	**54**	81	144	98	137	117	84	104	86	118	Met
Bacterial SCP	97	134	89	**59**	115	107	115	138	71	83	84	118	Cys
Meat meal	73	124	**61**	113	109	111	89	69	90	94	145	94	Met
Meat & bone meal	77	128	**59**	89	109	113	88	**60**	86	100	150	88	Met
Blood meal	**69**	158	**33**	**52**	**24**	162	124	**69**	89	214	**62**	123	Ils
Liver meal	76	135	72	89	105	121	109	106	71	98	105	153	Lys
Poultry byproduct meal	76	125	81	141	132	123	80	**60**	71	87	134	112	Tyr
Feather meal	91	164	**24**	289	131	124	78	86	**33**	**50**	147	76	Met
Earthworm meal	107	99	106	**52**	112	124	84	108	79	125	98	82	Cys

1/ Chemical scores based on comparison with the mean essential amino acid requirements of rainbow trout and common carp (Ogino, 1980). Mean EAA requirement (expressed as % of total EAA) being: threonine 10.6, valine 9.5, methionine 5.4, cystine 2.7, isoleucine 7.5, leucine 13.5, phenylalanine 9.5, tyrosine 6.5, lysine 16.8, histidine 4.8, arginine 11.6 and tryptophan 1.7

2/ Adapted from Tacon (1992)

3/ Numbers marked in bold and underlined represent limiting essential amino acids (present below 30% mean fish requirement)

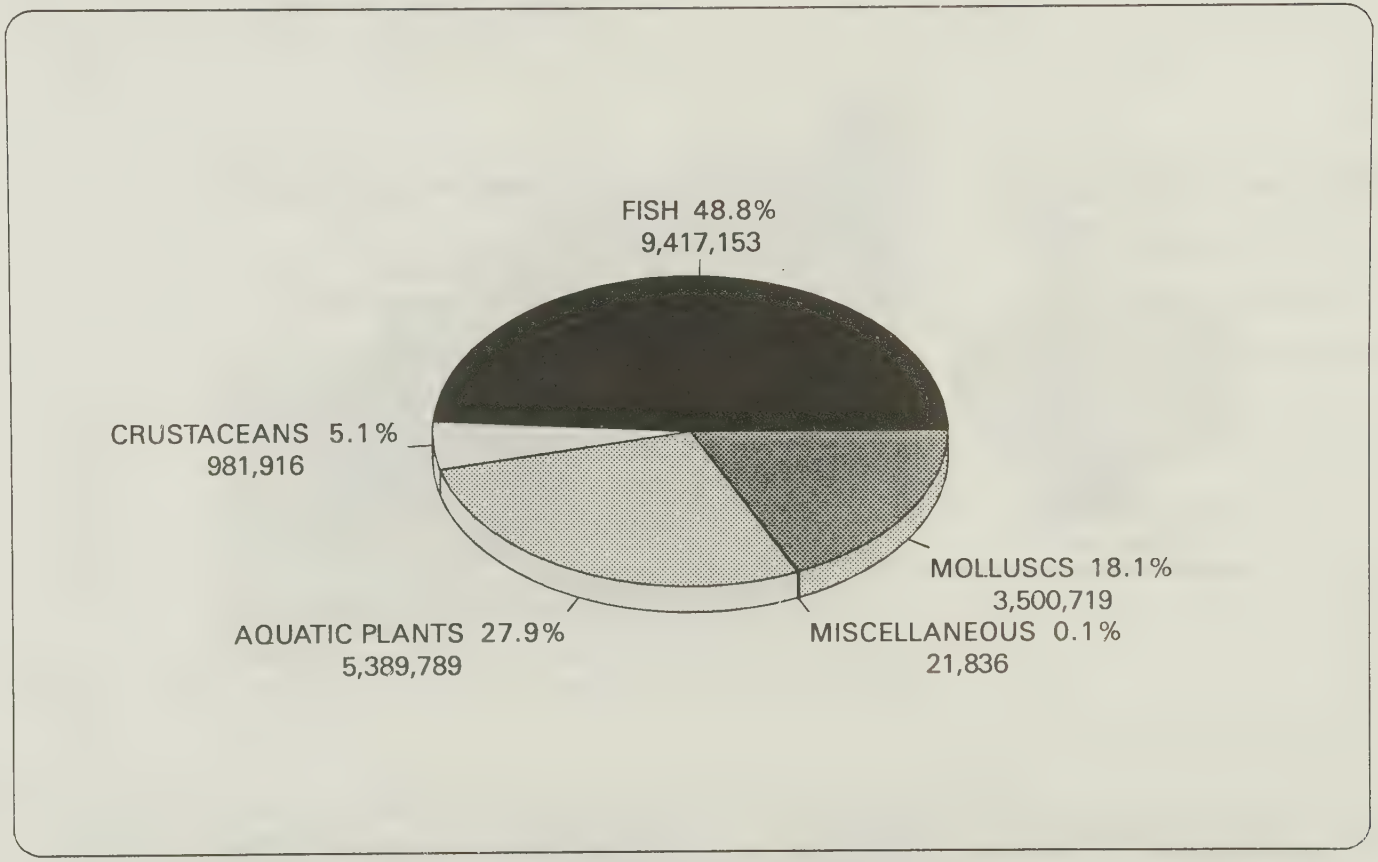
FIGURE 1. TOTAL WORLD AQUACULTURE PRODUCTION 1984-199



Total world aquaculture production in 1992 was 19,311,413 mt; fish 9,417,153 mt 48.8%, aquatic plants 5,389,789 mt 27.9%, molluscs 3,500,719 mt 18.1%, crustaceans 981,916 mt 5.1%, other 21,836 mt 0.1%. Total value of aquaculture production US $ 32,518,202,000 (FAO/FIDI, 1994)

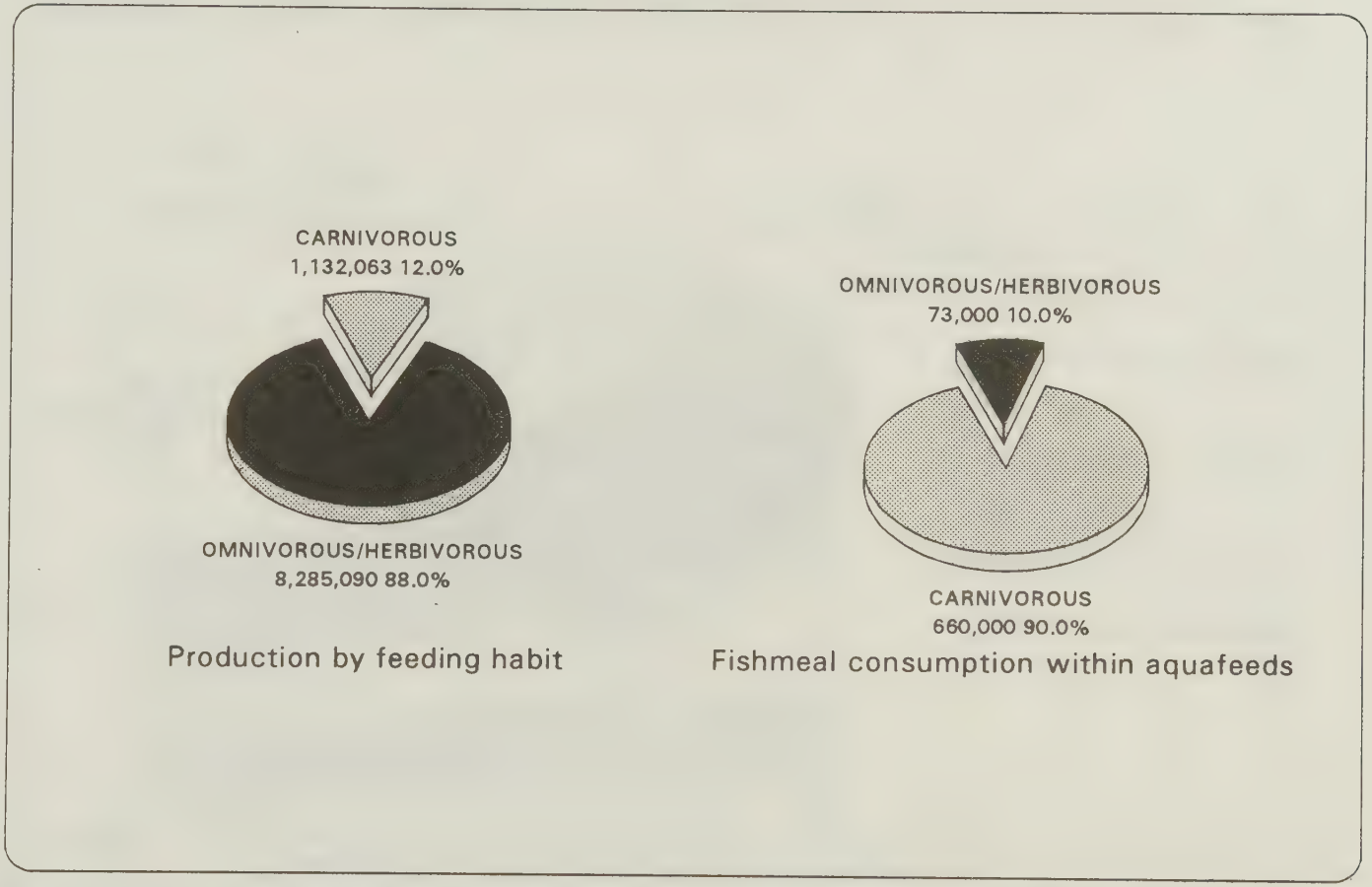
FIGURE 2. TOTAL WORLD AQUACULTURE PRODUCTION BY WEIGHT IN 1992

(values given as % of total and in metric tonnes)



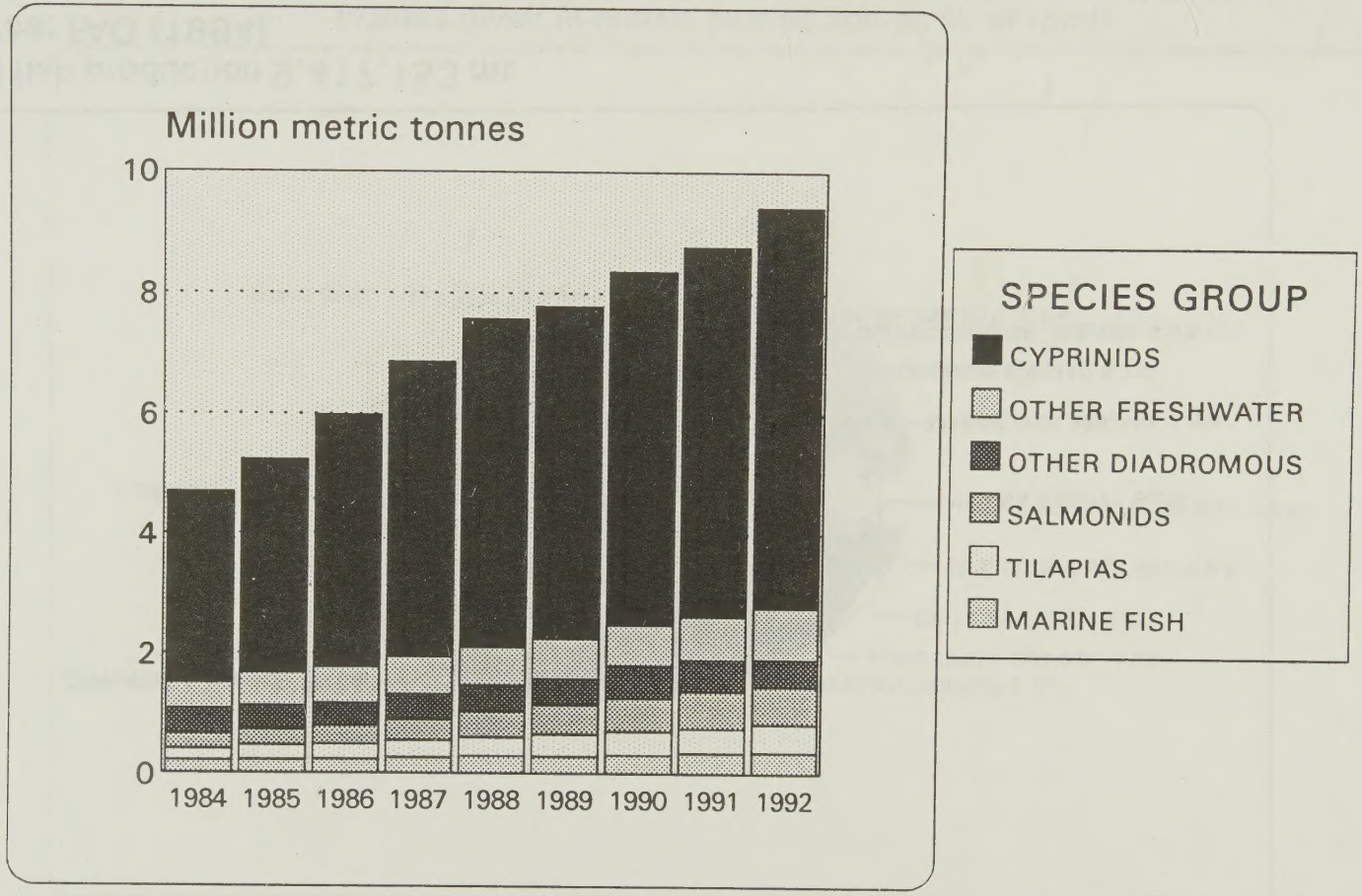
Total aquaculture production - animals & plants 19,311,413 mt
Total value of aquaculture production 32,518,202,000 US $; fish 53.3%, crustaceans 20.3%, aquatic plants 15.1%, molluscs 11.3%, other 0.1% (Source: FAO/FIDI, 1994)

FIGURE 3. FEEDING HABIT AND ESTIMATED FISHMEAL CONSUMPTION OF FARMED FINFISH IN 1992
(values given as % and metric tonnes)



Carnivorous fish species include all marine fish (except mullets, rabbitfish), diadromous fish (except milkfish, sturgeon), snakehead, pike, pikeperch & mollusc-eating freshwater fish (blackcarp)
Source: Fish production - FAO/FIDI (1994); Fishmeal usage - Tacon (1993)

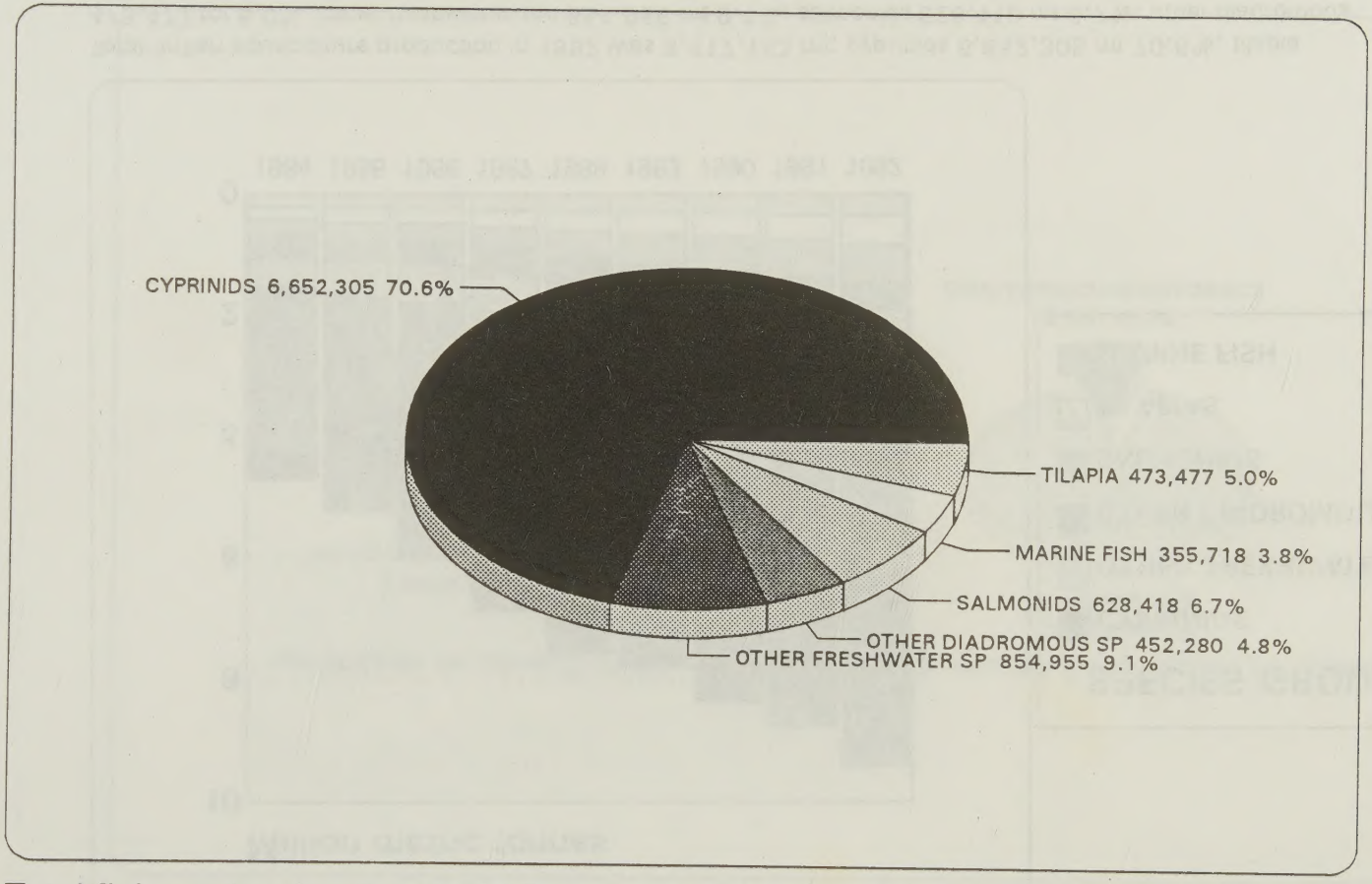
FIGURE 4. FINFISH AQUACULTURE PRODUCTION BY MAJOR SPECIES GROUPS 1984-1992



Total finfish aquaculture production in 1992 was 9,417,153 mt; cyprinids 6,652,305 mt 70.6%, tilapia 473,477 mt 5.0%, other freshwater spp 854,955 mt 9.1%, salmonids 628,418 mt 6.7%, other diadromous spp 452,280 mt 4.8%, marine fish 355,718 mt 3.8% (Source: FAO/FIDI, 1994)

FIGURE 5. WORLD AQUACULTURE PRODUCTION OF FISH IN 1992

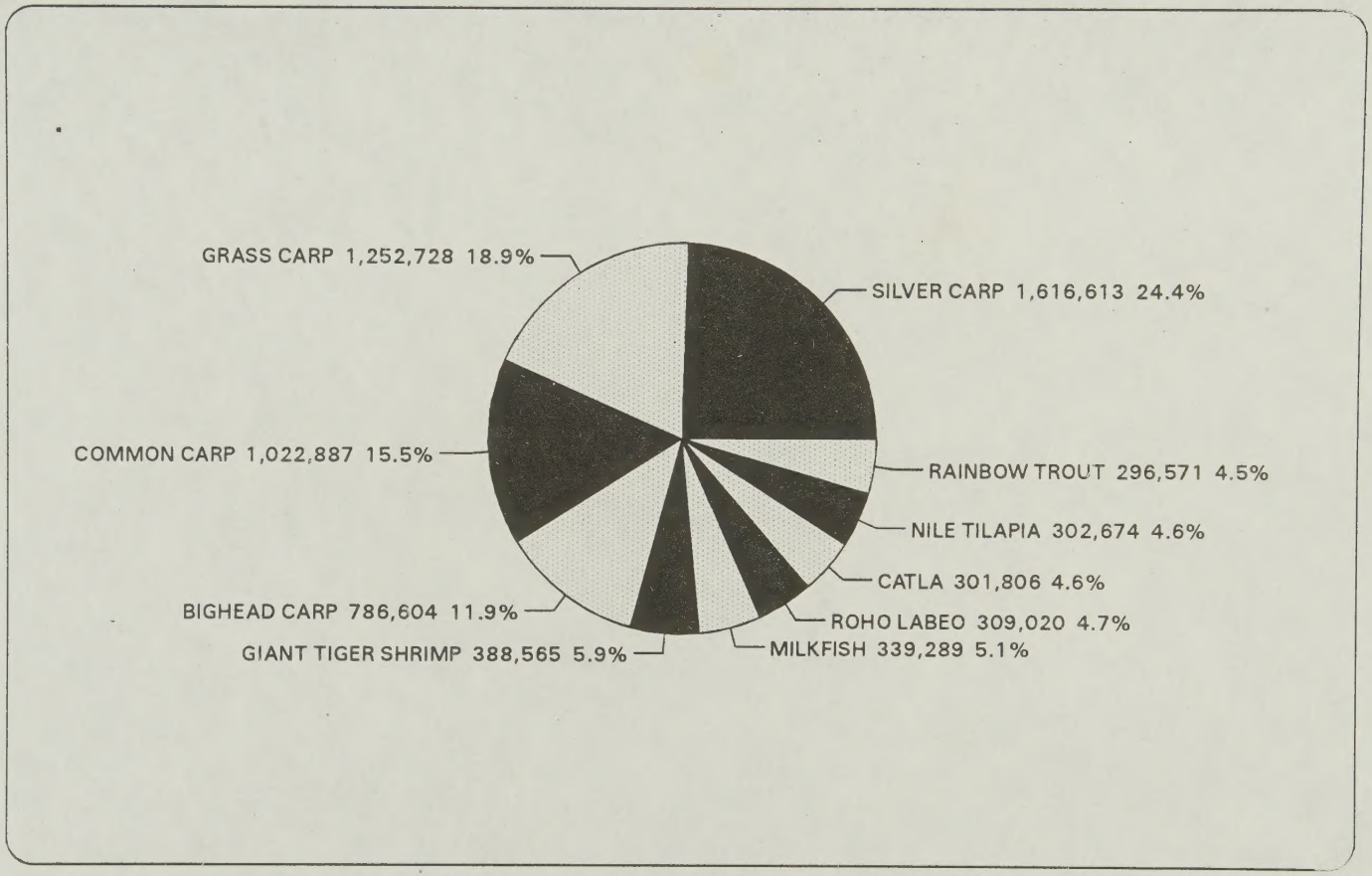
(values given in metric tonnes and as % of total)



Total fish production 9,417,153 mt
Source: FAO (1994)

FIGURE 6. TOP TEN CULTURED FISH AND SHRIMP SPECIES IN 1992

(values given in metric tonnes and as % of total)



Total production 6,616,757 mt or 63.6% of all cultured fish and crustaceans and crustaceans
Source: FAO (1993)